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INFORMATION CIRCULAR

DUST-EXPLOSION HAZARDS IN PLANTS PRODUCING OR HANDLING ALUMINUM, MAGNESIUM, OR ZINC POWDER

BY

HYLTON R. BROWN

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By Hylton R. Brown[2]

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INTRODUCTION

Although extensive research has been carried on to determine the factors affecting the explosibility of carbonaceous dusts, and much has been published on coal-dust and grain-dust explosions, recent reports of loss of life and property i explosions of metal dusts emphasize the lack of information on the extent of the dust-explosion hazard in plants manufacturing or handling aluminum, magnesium, or zinc powder, as well as other metal or mineral dusts. Early investigators believed that only the carbonaceous dusts formed explosive mixtures with air, and it was not until near the beginning of the present century that the explosibility of certain metal and mineral dusts was recognized generally. In his book, entitled "Fire and Explosion Risks," published in 1904, Von Schwartz called attention to such hazards.

Many vague references to metallic-dust explosions are found in the literature, such as "a severe explosion of aluminum dust occurred in the Middle West several years ago," but very little information seems to be available on the extent of the hazard, the number of explosions, or the amount of loss caused by explosions in plants handling metallic or mineral dusts or powders other than those of a carbonaceous nature. A search of the records of insurance companies, rating bureaus, fire underwriters, and fire-protection associations as well as the files and records of Government agencies has been made to obtain authentic data on explosion losses. To indicate the extent of the hazard a summary of laboratory tests covering the explosibility of certain metal dusts, with brief reference to their uses and methods of manufacture, and the data compiled from the information available on losses are presented in this publication.

LABORATORY RESEARCH

Many investigators have conducted laboratory tests with aluminum powder, and some information is available on the explosive properties of magnesium and zinc. Some of the work on ignition temperatures, explosive limits, pressures produced, and any peculiarities noted in connection with these investigations is reviewed briefly.

ALUMINUM POWDER

Uses

Aluminun powder is known generally as aluminum bronze and is used widely in the manufacture of paint, in printing and the preparation of aluminum-coated paper, in the manufacture of fireworks and flashlight powder, for protection of balloon and dirigible fabric, in welding compounds, and to a small extent in the manufacture of plastics or other materials where special decorative effects are desired.

Manufacture

Some aluminum powder is produced by the atomization process, in which the molten metal passes over a stream of air or gas; but such material is not suitable for printing or use in paint owing to the shape of the particles, and most of the aluminum powder now manufactured is prepared by stamping. In this process aluminum scraps or sheets are placed in the stamp mills, where steel hammers reduce the aluminum to powder or fine flakes, virtually all of which will pass through a 200-mesh sieve.

Ignition Temperature

There is some variation in ignition temperatures of aluminum powder as determined by different investigators. Stockmeier (1) gives the ignition temperature as 480° to 490° C. but states that the finest aluminum powder may ignite at 230° C. Leighton (2) failed to get an ignition of either 50- or 100-mg. samples in the Clement-Frazer apparatus at temperatures of 800° to 1,200° C. but was able to ignite it at 800° C. when a larger source of ignition was used. In a publication of the engineering department of the Factory Insurance Association, Hartford, Conn., (3) the ignition temperature of aluminum dust is given as 1,697° F. (925° C.). Trostel and Frevert (4) reported ignition of aluminum dust in the Clement-Frazer bomb with the glower at a temperature of 925° C. Ignitions by an induction-coil spark at 6.5 volts and 3 amperes were reported also by Trostel and Frevert. Beyersdorfer (5) gives 485° C. as the ignition temperature of aluminum powder and 230° C. as the ignition temperature of aluminum grindings. Ritter (6) refers to mechanical work in the form of shock, collision, or friction, and mechanically produced heat and sparks as sources of ignition and states that such ignitions have been known to occur. The author has ignited aluminum-dust clouds by sparks produced when a piece of steel was held in contact with a grinding wheel.

Explosive Limits

Explosive limits for aluminum dust as reported by different investigators vary widely. From tests with a new apparatus which they developed and which they claim produces a uniform distribution of the sample, Mason and Taylor, (7) set the lower limit between 40 and 50 mg. per liter. Bauer (8) reported the lower limit as 432 mg. per liter. Trostel and Frevert (4) reported ignitions of aluminum dust at concentrations of 7 mg. per liter when the glower or electric arc was used as a source of ignition and 13.7 mg. per liter when the induction spark was used. Matla (9) reported the lower explosive limit for aluminum dust as 28 mg. per liter. A description of the apparatus and method used by Bauer (8) indicates that some of the dust used in the tests may not have been in suspension, and the concentration cited would accordingly be too high. Gliwitzky (10) reports 0.04 gram or 40 mg. per liter as the approximate minimum explosive concentration of aluminum dust.

Pressures Developed

All investigators mention increases in pressure as the concentration is increased but with considerable variation when the particle size of the sample differs. Within the range used by most of the investigators the pressure rise is almost directly proportional to the concentration when similar dust is used, but Mason and Taylor (7) call attention to the fact that approximately 300 mg. of aluminum powder will consume all of the oxygen in 1 liter of air at room temperature and pressure. Gliwitzky (10) reports that the maximum pressure increases and the time required to reach the maximum decreases as the size of the particle is decreased. For particles of size 1.3, 0.6, and 0.3 microns the pressures were 7.7, 8.6, and 10.6 atmospheres and the time was 0.06, 0.03, and 0.012 second, respectively, with a concentration of 0.7 gram of dust per liter. The maximum pressure obtained in aluminum dust and air explosions was 11.6 atmospheres. Edwards and Leinbach (11) determined the maximum pressure, the average rate of pressure rise, and the maximum rate of pressure rise in a series of tests with aluminum dust at concentrations of 100 and 500 mg. per liter. The maximum pressure recorded was 23 pounds per square inch with the 100-mg. concentration and 40 pounds per square inch with the 500-mg. concentration. At these concentrations the average rate of pressure rise was 170 and 240 pounds per square inch per second, and the maximum rate of pressure rise was 513 and 724 pounds per square inch per second, respectively. It is this rapid rate of pressure rise that makes the control of aluminum-dust explosions by the release of pressure through building vents, such as those applicable to carbonaceous dusts, exceedingly difficult. The Factory Mutual Laboratories (12), in recent tests made with a 200-mesh sample of aluminum dust and an improved method of dispersing the dust, report pressures as high as 56 pounds per square inch, while cornstarch, considered one of the most explosive carbonaceous dusts, tested under the same conditions produced 30 pounds per square inch.

Peculiarities Noted in Investigations

Zimmerman (13) reports that flash lamps containing aluminum foil and oxygen can ignite the aluminum foil in similar bulbs at a distance of 10 to 20 cm. through an interposed screen of moistened cellophane. Wolf (14) claims that where aluminum foil or powder is produced it can be ignited not only by fire or sparks but also by the effect of light. Several investigators state that the inflammability of aluminum depends on the surface exposed. Reference is made in a number of articles to the decomposition of water into hydrogen and oxygen by aluminum powder and the possibility of ignition and explosion of the hydrogen. Decomposition may occur at temperatures as low as 30° C. Stockmeier (1) also calls attention to the increased explosion hazard if oxygen carriers are present. Ordinarily stable under friction, aluminum powder explodes violently with gentle rubbing after the addition of potassium chlorate. Even in a coarsely divided state amalgamated aluminum ignites immediately upon exposure to air.

MAGNESIUM POWDER

Magnesium, a light, brilliant, silver-colored metal just a little softer than aluminum, has received considerable attention in recent years because of its increased use in construction where lightness with strength is desirable, as in the airplane industry. Although the explosion or fire hazard is present in the machining of castings and the storage or handling of turnings and scrap, the principal danger occurs in the manufacture and use of the powder.

Uses

The principal use of magnesium powder is in flashlight powder, fireworks flares, star shells, illuminating shells, tracer bullets, and the production of smoke screens. In such uses it may be combined with aluminum or other metallic powders. In powdered form magnesium is also used as plant food for tobacco, potatoes, cotton, etc.

Manufacture

Almost the entire quantity of magnesium powder used in the United States before 1917 was imported, but in that year an American process of manufacture was developed, and since 1922 imports have been negligible. Production has varied with domestic requirements and the export demand, which is increasing. The powder is produced in different types of mills and ranges in size from 30-mesh to 265-mesh or finer. The 200-mesh or finer sizes usually are specified for flashlight powder. In addition to magnesium powder, commercial flashlight powder may contain barium nitrate, potassium chlorate, or other materials. All magnesium in this country is produced by one company, but about 30 other companies are licensed to fabricate it, and a number of these manufacture the powder.

Ignition Temperature

The ignition temperature found by different investigators varies for magnesium as it did for aluminum. The literature available is more limited, and methods of determining the ignition point are not always given. The most complete report is given by Brown (15) in a dissertation on The Determination of the Ignition Temperatures of Solid Materials. The method of making the tests is described in detail, and the data show that magnesium in the form of small pieces of ribbon 0.2 by 3.0 mm. ignited at 507° C. A report on the inflammability of magnesium by the Factory Mutual Laboratories (12) states that where an entire piece of the metal can be raised to a temperature of about 930° F. (499° C.) ignition will take place. In an article on the magnesium industry Gann (16) points out that the ignition temperature drops rapidly as particle size decreases but gives no ignition temperature for the fine dust. It is known that metallic or electric sparks have produced ignitions of magnesium powder, and the dust ignites readily in the Clement-Frazer apparatus with the coil at 900° to 1,200° C. Although no tests have been reported on the determination of the ignition temperatures of magnesium and aluminum dust clouds under similar conditions, comparison of the data available indicates that the fine magnesium powders may be ignited at temperatures below those required to ignite the finer sizes of aluminum powder.

Explosive Limits

Little information is available in the literature searched on the explosive limits of magnesium powder, and about the only means of determining approximate limits is by comparison with other dusts. In the most recent tests of magnesium powder by the Factory Mutual Laboratories (12) pressures of 14 pounds per square inch were produced at concentrations of only 50 mg. per liter or 50 ounces per thousand cubic feet. This would indicate that the lower limit probably is well below the limit determined by several investigators for aluminum powder - 40 mg. per liter. The curve drawn from pressures obtained in magnesium-dust explosions at different concentrations flattens and shows little or no increase in pressure at concentrations above 312 mg. per liter. As no decrease in pressure was noted when the concentration was increased to 380 mg. per liter, it was not possible even to approximate the upper limit. Edwards and Leinbach (11) obtained explosions and recorded high pressures at concentrations of 500 mg. per liter. Improved methods now being developed for obtaining uniform concentrations of dust in air undoubtedly will allow more accurate determination of explosive limits.

Pressures Developed

Extraordinarily high pressure develops in explosions of magnesium powder or dust from magnesium alloys. Edwards and Leinbach (11) report a pressure of 40 pounds per square inch in tests at a concentration of 500 mg. per liter and a maximum rate of pressure rise at the same concentration of 788 pounds per square inch per second. In tests made by the Factory Mutual Laboratories (12) magnesium dust developed a pressure of 68 pounds per square inch, or nearly double the pressure of aluminum or cornstarch under similar conditions; as heretofore indicated the pressures obtained from similar experiments with cornstarch are higher than with other carbonaceous dusts.

Peculiarities Noted in Investigations

Although magnesium is not attacked by water at room temperature, it is slowly decomposed by water at 100° C. with the formation of hydrogen. Dilute acids may cause a violent evolution of hydrogen. In machining metal parts surrounded by magnesium or magnesium-alloy castings, sparks or heat produced by the machine tool may ignite the dust or chips and cause a hot fire. In one instance reported, sparks from a grinding wheel ignited magnesium dust and caused an explosion that killed three men and injured several others.

ZINC POWDER

Uses

More than 11,000 tons of zinc powder were produced in 1938, of which somewhat over 2,000 tons was exported. It is used principally to precipitate and recover gold and silver from cyanide solutions but also is used largely in dye plants. It may be mixed with aluminum, magnesium, and other powders in making fireworks and smoke screens. A limited amount is used for plant food.

Manufacture

Virtually all zinc dust is produced by redistillation of zinc dross and slab zinc, and the product as marketed usually is very fine. More than 99 percent of the powder in the samples tested passed through a 200-mesh screen.

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Ignition Temperature

The amount of information available on the explosibility of zinc dust is quite limited. One report indicates that the powder ignites at about 360° C. Owing to its weight, zinc dust does not readily form a cloud in air, but it can be ignited easily in the Clement-Frazer apparatus either with the coil at 900° to 1,200° C. or with the magnesium-barium peroxide pellet, which is calculated to produce a temperature of about 1,800° C.

Explosive Limits

One investigator reports that he obtained an explosive mixture by blowing 4 grams of zinc dust into suspension in an open-end tube by releasing about 33 cubic inches of air at 10 to 50 cm. of mercury. Not enough additional data are given for even an estimate of the actual concentrations obtained in such tests. Edwards and Leinbach (11) obtained ignitions at concentrations of 100 and 500 mg. per liter. Later tests indicate that owing to the weight of the dust and the method used to throw it into suspension the concentration at the point of ignition may have been below that indicated.

Pressures Developed

In the few reports available on explosion tests with zinc powder the earlier results indicate that the pressures developed are comparatively low. Edwards and Leinbach (11) report pressure of only 3 pounds at a concentration of 100 mg. per liter and 8 pounds at the 500-mg. concentration. One other report gives a pressure of 4.5 pounds at a concentration of 5 grams per liter of air. Recent developments indicate that the low pressures obtained undoubtedly were due to unsatisfactory methods of producing a uniform concentration of zinc dust in air. With an improved method of producing the dust and air mixture in the Clement-Frazer apparatus, the Factory Mutual Laboratories (12) recently obtained pressures of 23 pounds per square inch in tests with samples of zinc powder containing 92 percent metallic zinc.

Peculiarities Noted in Investigations

Most of the investigators call attention to the fact that water oxidizes zinc dust at ordinary temperatures and liberates hydrogen. One report indicates that enough heat may be produced in the decomposition to ignite the hydrogen or near-by zinc dust. Manufacturers make a special effort to keep the powder dry, and, by a warning printed on the container label, some of them caution users against the danger of getting the material wet.

EXTENT OF THE HAZARD

An accurate appraisal of the extent of the explosion hazard in connection with the manufacture of aluminum, magnesium, and zinc powder is difficult because many of the powder-producing plants are operated as a part of an establishment engaged in the manufacture of a number of metal products. The dust or powder may be considered a byproduct at some plants, and the losses caused by explosions and fires in the powder-producing sections of metal plants have been listed separately or classified by insurance companies or rating bureaus in very few instances. From examination of the records, however, it is quite evident that small fires occur in such plants much more frequently than is generally supposed. Since any fire in the metallic dusts mentioned is the potential beginning of a serious explosion, and laboratory tests have demonstrated the ease with which these dusts can be ignited, it may be concluded that the explosion hazard exists wherever aluminum, magnesium, or zinc powder is manufactured or handled.

In a book entitled "Dust Explosions," Price and Brown included 84 plants in their tabulation of dust-producing industries in which the hazard of aluminum-dust explosions existed. More than 11,000 persons were employed in these plants, and the value of their products was approximately $70,000,000 annually. Magnesium- and zinc-powder manufacturers were not listed separately, but recent reports indicate that there are about 30 such plants. Although relatively few plants actually may be producing the powders the explosion hazard exists in hundreds of establishments owing to the handling or use of the powders in paint mixing, printing, and the numerous manufacturing processes. The record of explosion losses in such processes clearly indicates the necessity of developing protective measures to guard against dust ignitions.

A review of the literature and of such records of metal-dust explosions as are available indicates that during the last 23 years - 1917 to 1939, inclusive - there were at least 45 explosions of aluminum, magnesium, and zinc powder in which the losses were serious enough to be reported in newspapers or other publications. Reports frequently refer to other minor explosions having occurred previously.

An examination of the 45 explosions reported shows that 44 lives were lost, 58 persons were injured, and the property loss exceeded $1,700,000; 30 of these were explosions of aluminum powder, and it is significant to note that 12 of the 30 occurred during the last 5 years.

Increased use of both aluminum and magnesium powder has veen noted during recent years, and the production of primary magnesium in 1939 was more than double the production in 1938. This increased production undoubtedly indicates greater use in cast parts, the machining of which creates a fire and explosion hazard. A report received from England describes a disastrous fire in a 15-ton pile of magnesium filings and cuttings at Honslow early this year. The fire lasted for nearly 24 hours, and 14 men of the fire department were injured seriously in explosions that occurred while they were endeavoring to protect adjoining sheds containing large stores of aluminum and magnesium turnings, iron filings, and possibly magnesium dust. This is but one of many fires that may occur in plants manufacturing war supplies, automobile engines, and airplane parts, and represents a condition requiring special precautions to prevent ignitions and guard against explosions. Because this loss occurred in Europe and is listed as a fire, it has not been included in the tabulation of explosion losses previously given.

EXPLOSION PREVENTION AND PROTECTION

In a plant where a spark or small fire may cause a serious explosion, fire prevention and fire protection are of the utmost importance; providing such protection, under conditions where the use of water and the common types of fire extinguishers serves only to intensify the fire, is a difficult problem. At present no satisfactory and safe method can be recommended for extinguishing a large fire in aluminum, magnesium, or zinc powder. Water causes oxidation, and the release of hydrogen, hose streams, or gas jets may throw dust into suspension and form explosive dust and air mixtures, and inert gas atmospheres that may retard ignition are ineffective in extinguishing fires that are well-started. Violent explosions of magnesium powder have occurred in atmospheres in which the oxygen had been reduced to as low as 12 percent. The problem calls for research and experimentation and the development of a satisfactory method of combating the hazard. Small fires can be extinguished by using sand, talc, or rock dust. By forming a dike or ring about the burning powder the fire can be segregated and allowed to burn itself out. Great care must be taken to avoid disturbing the burning powder when applying the sand or talc, and only men familiar with the explosion hazard should attempt to employ this method.

Protection becomes largely a question of fire prevention, although a few recommendations based upon the results of laboratory studies can be made.

Cleanliness is of the utmost importance, and dust should not be allowed to accumulate where it might be thrown into suspension in air and form an explosive mixture.

Powders should be kept dry to prevent heating and possible ignition.

All equipment should be grounded to prevent accumulation of charges of static electricity.

Precautions should be taken to prevent the formation of metallic or electric sparks.

All electric wiring and equipment should be of the type approved for use in atmospheres containing explosive metal dust, and remote control of electric circuits is desirable.

Magnetic separators should be used to remove tramp iron or other foreign material that might produce sparks in the mills or polishers.

Use of open flames and smoking should be prohibited.

Nonsparking tools should be used for repair work and for other activities as far as possible.

Heating should be by hot air only, with provision for heating the air with steam coils located outside the dust-producing section.

To reduce the hazard from fire and explosion it is recommended that the powder-making section of a plant be segregated from other parts or buildings and divided into small units.

Buildings used for powder-making should be only one story, with a roof as light as practical and arranged to lift off readily in case of an explosion.

Buildings should be separated by not less than 50 feet of space with powder-making buildings at least 300 feet from occupied structures such as dwellings, stores, or public buildings.

Dry sand, talc, or other powders to be used to extinguish small dust fires should be stored in clearly marked or indicated containers at strategic points.

Fire companies that may respond to alarms from the metal-powder-producing section should be warned against the use of water or extinguishers that may disturb the dust or intensify the fire.

NEED FOR ADDITIONAL RESEARCH

Study of this problem emphasizes the need for development of some effective method of fighting fire and preventing explosions in plants producing or handling aluminum, magnesium, or zinc powder or scrap. As the captain of the fire company pointed out in his report on the magnesium fire in England referred to above, he had nothing but water to use in protecting the buildings containing large stores of aluminum and magnesium powder that were endangered by the fire in a pile of magnesium scrap. Although successful in preventing the ignition of the nearby buildings, it was at the cost of injury to 14 of his men, who were caught in explosions caused when spray from their hose lines fell on the burning magnesium. Increased production and use of aluminum, magnesium, and zinc powder and scrap will make it imperative that an answer be found to the question, How can explosions of aluminum, magnesium, and zinc powder be prevented and how can fires in plants producing or handling these products be extinguished safely? Research is being planned to try to provide the answer.

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